Maico Report No. R-503

FINAL REPORT

FOR

FEASIBILITY STUDY OF AN ELECTRONIC GONIOMETER SWITCH

Contract No. NObsr-81313

Index No. SS 024001, ST-6

18 April 1960 to 18 December 1960

February 28, 1961

Maico electronics inc.
a subsidiary of w. a. sheaffer pen company

Twenty-One North Third Street
Minneapolis • Minnesota

MAICO ELECTRONICS, INC.
21 North Third Street
Minneapolis 1, Minnesota

Maico Report No. R-503

FINAL ENGINEERING REPORT

FOR

FEASIBILITY STUDY OF AN

ELECTRONIC GONIOMETER SWITCH

Contract No. NObsr-81313

Index No. SS 024001, ST-6

18 April 1960 to 18 December 1960

February 28, 1961

Prepared by: John Foreman
J Foreman - Project Engineer
(Detection Section)

Approved by: A. N. De Sautels
A. N. DeSautels - Director
(Research Department)

Maico Report No. R-503
February 28, 1961

TABLE OF CONTENTS

ILLUSTRATIONS AND TABLES

Maico Report No. R-503
February 28, 1961

FINAL ENGINEERING REPORT

FEASIBILITY STUDY

OF AN

ELECTRONIC GONIOMETER SWITCH

ABSTRACT

This is the final report required under contract and covers the period from 18 April 1960 to 18 December 1960. The work described in this report covers the one-month extension of feasibility from 18 November 1960 to 18 December 1960.

Final design specifications for the amplifier were established and amplifiers were constructed that show consistently better performance than these minimum specifications. The most notable improvement is in the area of noise reduction, with noise figures ranging from 3.2 to 5.3 decibels. With measurement of linearity and flatness of band width, amplifier feasibility has been demonstrated in all areas of performance.

Transistors are available that provide high quality amplifier performance without selection. Lower cost transistors are available that provide borderline acceptable performance.

Point-contact diodes were tested that have a high degree of linearity and prove suitable for diode gates.

System logic and interpolation feasibility were established in the second interim report.

PART I

A. PURPOSE

To conduct a feasibility study of an electronic goniometer switch which will:

1. Simultaneously detect the inputs from a quantity of antennas and amplify the r-f signals with a minimum of noise.
2. Simultaneously direct these signals through delay lines in synchronization with the 360 degree sweep of an oscilloscope indicator; and
3. Provide parameters in conformity with the requirements of Wullenweber equipment.

The work done under this contract is complementary to that being done by the Radio Direction-Finding Research Group at the University of Illinois under Contract NObsr-64723, Index No. NE-070154, Subtask 16.

B. GENERAL FACTUAL DATA.

Personnel assigned full or part time to this project during the contract period:

A. N. DeSautels
J. J. Foreman
J. V. Gilles
3 Technicians

Total Man hours for the contract period: 3168 (engineers and technicians).

References for assumptions used in computations and report discussion are included in the first Interim Report, No. R-489, dated August 25, 1960.

C. DETAIL FACTUAL DATA

1. General.

During the one month extension of feasibility, additional studies were made on amplifier noise figure, solid-state components, and diode gate linearity along with transistor gate feasibility. Details of these studies are included in the following paragraphs C2, C3, and C4. Interpolation and system logic were considered feasible at the time of the second interim report and were discussed or referenced in that report.

2. High Frequency Broadband Amplifiers.

a. Design Approaches. In the development of an feasible amplifier design, increased linearity, flat frequency response, and reduction of noise have been major design goals. Test results of the latest amplifier designs show acceptable figures in these areas. The following are the established minimum design specifications for the amplifier.

E_{in}	0 to 0.25 Vac
Voltage gain	4
Bandwidth	2 mc to 30 mc, flat
Linearity	1 part in 200, max nonlinearity (-46 db)
Noise figure	7 db or less

A schematic diagram of a typical satisfactory amplifier is shown in figure 2 of Interim Development Report II (Maico Report No. R-501, December 14, 1960). The physical layout of this amplifier design is illustrated in the printed wiring board configuration of figure

1 of the report. Most recent measurements show a noise figure between 3.2 and 5.3 decibels, intermodulation products that are down between -46 and -61 decibels, and a change in amplitude between 2 and 30 megacycles that is less than 0.25 decibels per octave.

Figure 1. Amplifier Printed-circuit Design

b. Performance characteristics. During the one month extension of feasibility, additional measurements and evaluations were made of noise figure, phase shift, and intermodulation products.

Noise figure measurements were made using the method described in Appendix B of the second interim report (Maico Report No. R-501). This same report shows the basic amplifier schematic used for the tests (figure 2), and identifies the transistor manufacturer and type (pages A9 and A10).

The 50 series transistors listed in the following table 1 are Texas Instrument's 2N706B units. The following table shows noise figure measurements using various combinations of transistors, gains, and values of R2. Lowest noise figure values were obtained with the Motorola 2N706B.

R_2 in ohms	Transistor numbers Q1	Q2	Q3	Q4	Noise figure in db	Voltage gain (2-30mc)
51	83	17	14	15	4.6	5
51	83	17	14	15	5.0	6
51	83	17	14	15	5.3	7
25	83	17	14	15	4.1	6
0	83	17	14	15	3.5	6
0	18	13	14	15	4.2	6
0	83	84	81	85	3.5	6
0	81	82	83	84	3.8	6
0	31	71	73	74	4.2	7
0	72	71	73	74	5.2	7
0	51	52	53	54	5.0	7
0	55	52	53	54	4.5	6
0	83	52	53	54	3.2	6

Table 1. Amplifier Noise Figure Measurements

Since a flat frequency response is determined by phase shift and phase shift is a function of attenuation, a mathematical determination can be made of the flatness of amplifier frequency response. In the equation-

$$B_c = \frac{\pi}{12}\left(\frac{dA}{du}\right)_c + \frac{1}{6\pi}\int_{-\infty}^{\infty}\left[\left(\frac{dA}{du}\right) - \left(\frac{dA}{du}\right)_c\right]\log_e \coth \frac{|u|}{2}\, du,$$

where b_c equals phase shift in radians at frequency f_c, and $\frac{dA}{du}$ equals slope of attenuation curve in decibels per octave, we can estimate the permitted amplitude variation for a four degree change in phase by approximating the equation with its first term. ~~Four degrees~~

~~change in phase by approximating the equation with its first term.~~ Four degrees (± two degrees) is chosen as a reasonable tolerance to establish a flat frequency response. Substituting the four degree tolerance value, the unknown of the first term becomes:

$$\left(\frac{dA}{du}\right)_c = \frac{4^\circ \times 12\text{db}}{180^\circ} \sim = 0.25 \text{ db},$$

where the gain of the amplifier is approximately equal to 12 decibels. The resulting allowable amplitude change for the amplifier is then 0.25 decibels per octave. The amplifier frequency response curves of figure A1, Appendix A, of the second interim report, show that between two and 30 megacycles, the change in amplitude is considerably less than 0.25 decibels per octave. The amplifiers, therefore, have a flat frequency response that is considerably better than the selected tolerance of plus or minus two degrees of phase shift.

Preliminary measurements were made on a dual channel oscilloscope to determine the amount of phase delay existing between different amplifiers. This method is accurate to within five to ten degrees, and should give sufficient results for feasibility purposes.

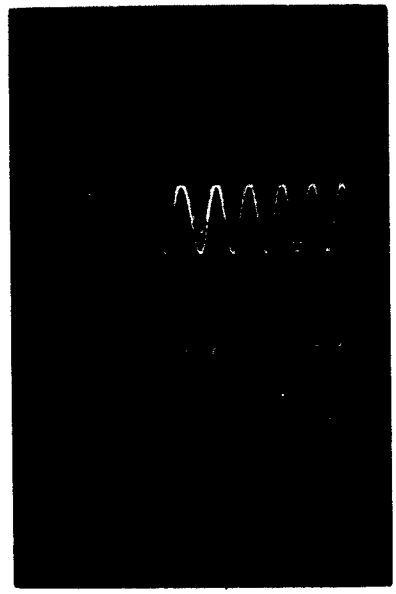
In the test setup for measuring phase delay, a signal generator output was fed simultaneously into two separate amplifiers. The amplifier outputs were than fed separately into the dual channel oscilloscope. Tests were made at 2, 10, 20, and 30 megacycles, using different combinations of transistors in the amplifiers. The results show no measurable phase delay between the different amplifiers. Pictures of the tests are shown in figure 2. Picture A was made by applying an amplifier output to both channels of the oscilloscope.

2 mc

10 mc

20 mc

30 mc



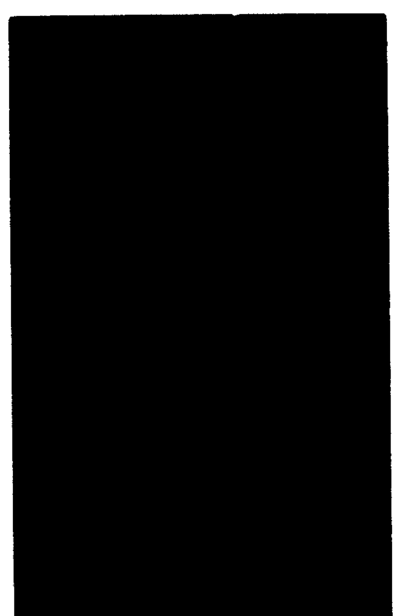
Picture "A"

30 mc

2 mc

10 mc

20 mc



Picture "B"

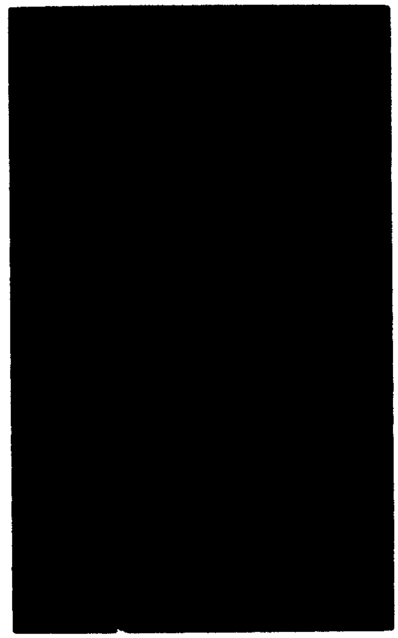
Figure 2, Sheet 1, Phase Delay Measurements

30 mc

20 mc

10 mc

2 mc



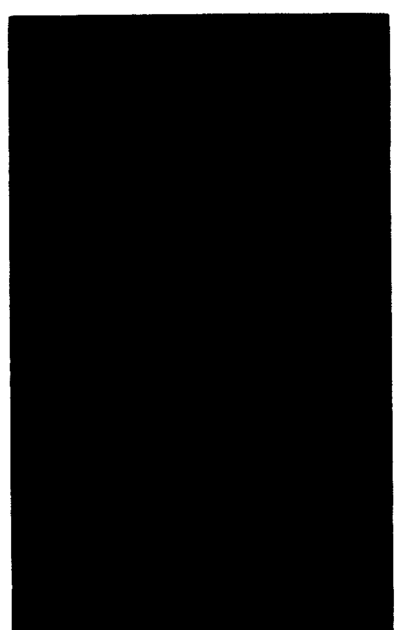
Picture "C"

30 mc

20 mc

10 mc

2 mc



Picture "D"

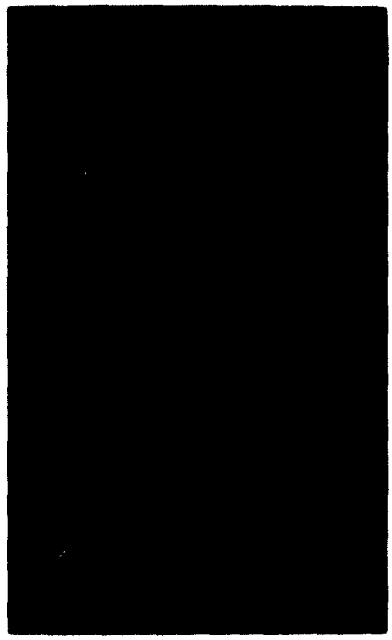
Figure 2, Sheet 2, Phase Delay Measurements

30 mc

20 mc

10 mc

2 mc



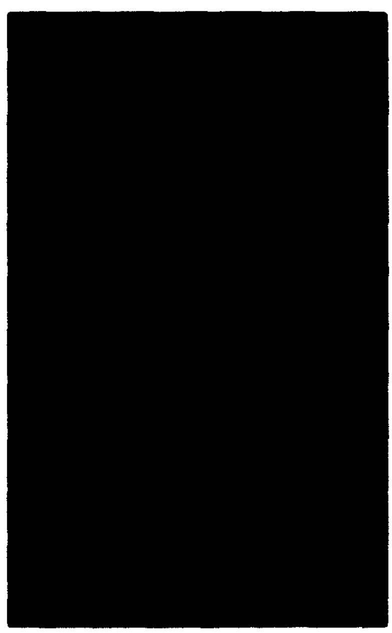
Picture "E"

30 mc

20 mc

10 mc

2 mc



Picture "F"

Figure 2, Sheet 3, Phase Delay Measurements

Pictures B thru F of figure 2 were made by comparing different amplifier outputs in each channel of the oscilloscope.

Additional measurements were made of second and third order intermodulation production using the method described in Appendix C of the second interim report. The transistor numbers of the following table 2 are also identified in the second interim report. A voltage gain of four flat from two to 30 megacycles was used for the amplifiers. The "E in" column shows the value of each of the applied fundamental voltages. Results as given in table 2 show acceptable distortion products for the different transistors that were used.

E in	IM product in db		Transistor number			
(rms)	2nd Order	3rd Order	Q_1	Q_2	Q_3	Q_4
0.25	-48.6	-46.0	18	13	14	15
0.2	-51.5	-53.5	18	13	14	15
0.1	-57.0	-59.0	18	13	14	15
0.25	-48.8	-46.	17	13	14	15
0.2	-50.5	-52.	17	13	14	15
0.1	-57.0	-60.	17	13	14	15
0.2	-51.	-52.	12	13	14	15
0.1	-58.	-60.5	12	13	14	15
0.25	-46.	-46.5	82	17	14	15
0.2	-49.	-51.	82	17	14	15
0.1	-55.	-60.	82	17	14	15
0.25	-51.5	-46.	81	82	14	15
0.2	-53.	-52.	81	82	14	15
0.1	-61.	-59.	81	82	14	15

Table 2. Intermodulation Products

3. <u>SOLID-STATE COMPONENTS.</u>

a. Amplifier components. The data collected to date shows that passive components are not critical. Components are selected that are normally used for high frequency applications.

In a comparative study of resistors, the metal film variety exhibited considerably less noise voltage than carbon resistors and did not have the inductive properties of precision wire resistors. Since the noise generated by the resistors was found to be insignificant when compared to transistor noise, the low-cost carbon resistor is sufficiently reliable for use in the amplifiers.

Zener diodes were unacceptable because of their high noise level. Noise measurements for all types tested varied between five and nine microvolts. Use of the zener diodes was eliminated in amplifier circuit design.

Of all the transistors evaluated, the 2N706A and B show superior frequency response, linearity, noise figure, and gain characteristics needed for the present applications. In addition the type 2N706B transistors that are made with the epitaxial process have better high frequency characteristics and a lower noise figure.

In an effort to find an acceptable low-cost transistor, a number of germanium PNP mesa transistors were tested. These were the Motorola 2N741 which are about one-fifth the price of the 2N706B. Amplifiers made with the 2N741 had to have the gain reduced to between three and four in order to have intermodulation products down to between 50 and 60 decibels. The lower gain has an adverse

effect on noise, and produces a noise figure between five and six decibels. While this performance is acceptable, it is not as good as the performance of the 2N706B.

b. Gate components. A final evaluation was made of bilateral transistors for use as gating circuit components. Texas Instruments' N219 and RCA bilateral transistors were used in these tests. These units provide 35 decibels of rejection for a single component, and 65 decibels (1000 to 1) of rejection when the switch is built with two transistors in series. These units have better rejection ratios than diodes, but are less suitable for gates because of their cost, high-frequency limitations, and the required increase in circuit complexity.

The most acceptable diode tested to date is the Hughs HD2764. This point-contact diode has excellent high-frequency performance and acceptable rejection qualities. These diodes have sufficient uniformity to eliminate the need for selection.

Linearity measurements were made of the HD2764 diode in a gating circuit similar to the one shown in figure B5, Appendix B, of the first interim report. Table 3 shows the results of these tests using a nine-megacycle input.

e_{in}	I_d d-c ma	% Harmonic Distortion	% Efficiency	Diode Numbers
88.5	4.6	.39	98.5	1 & 2
177	4.6	.36	97.5	1 & 2
354	4.6	.637	97.5	1 & 2
88.5	10	unreadable	unreadable	1 & 2
177	10	.266	99-100	1 & 2
354	10	.282	99-100	1 & 2
88.5	4.6	.395	97	3 & 4
177	4.6	.353	96	3 & 4
354	4.6	.614	97	3 & 4
88.5	10	unreadable	unreadable	3 & 4
177	10	.25	99	3 & 4
354	10	.254	99-100	3 & 4
88.5	4.6	.37	97.5	5 & 6
177.0	4.6	.294	96	5 & 6
354.0	4.6	.556	96.5	5 & 6
28.5	10	unreadable	unreadable	5 & 6
177	10	.237	99-100	5 & 6
354	10	.237	99-100	5 & 6
1.25	3	2.7	83	5 & 6
1.25	7	.78	99-100	5 & 6
1.25	10	.375	99-100	5 & 6
1.25	15	.198	99-100	5 & 6
1.25	20	.125	99-100	5 & 6
1.25	30	.075	99-100	5 & 6

Table 3, Diode Gate Linearity Measurements

4. Gating Circuits.

Diode gates have been selected as the most feasibl e choice at the present time. Gates using one to four diodes were constructed in order to evaluate cost factors against rejection ratios. A double diode gate provides suitable rejection ratios for the goniometer switch.

Studies of insertion loss using point-contact diodes indicate a constant forward resistance of five ohms for bias levels greater than ten milliamperes. This corresponds to an insertion loss of eight decibels. Noise voltage was found to be independent of bias current and frequency in the two to thirty megacycle range being considered.

Maico Report No. R-503
February 28, 1961

MAICO ELECTRONICS, INC.

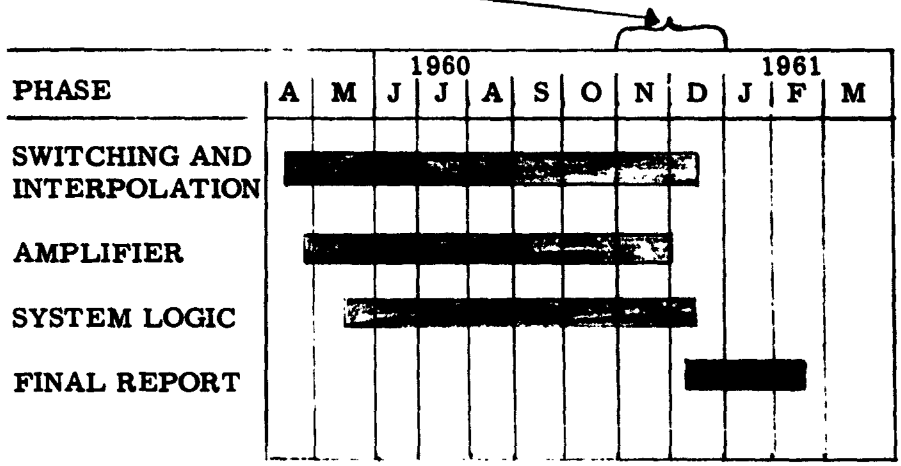
Project Performance and Schedule

INDEX No. SS. 024001, ST-6

D. PROJECT PERFORMANCE AND SCHEDULE

Contract No. NObsr-81313 Final Report Date 2/28/61

Period Covered 11/1/60 - 12/18/60



E. CONCLUSIONS

The eight-month study that is concluded with this report establishes the feasibility of a soldi-state electronic goniometer switch. This electronic switch would replace mechanical switches now being used in Wullenweber Direction Finding Systems.

Different aspects of the switch that were studied and that have shown demonstrated feasibility are broadband r-f amplifiers, diode gating circuits, and variable delay lines. Solid-state components for these items are available off-the-shelf components that do not require selection in order to insure uniform high quality performance between identical units.

System logic and circuit design have been developed that provide synchronization, scanning, and interpolation. These provide parameters in conformity with the requirements of Wullenweber equipment. Switching speeds and frequency range can be provided that extend beyond the range of existing Wullenweber installations.

PART II

RECOMMENDATIONS

Work done under Contract NObsr 81313 included the feasibility study of a solid-state electronic goniometer switch that would detect, amplify, and display the inputs from a quantity of antennas in conformity with Wullenweber equipment.

As a result of this work, Maico Electronics, Inc. recommends construction of an experimental-model electronic goniometer switch with provisions for inputs from 120 antennas. This switch would be compatible with the Wullenweber direction Finding System developed by the University of Illinois under Contract NObsr 64723, Index No. NE-070154, Subtask 16.